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THE SPECTRAL DISTRIBUTION OF THE LUMINANCE COEFFICIENT OF THE SEA IN WATERS WITH DIVERSE OPTICAL PROPERTIES

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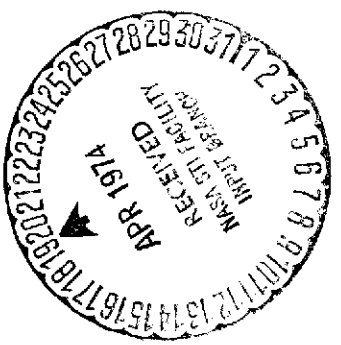

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16. Abstract

The hydrooptical characteristics which exert an influence on the coefficient of sea luminance are considered. These include the absorption index, the index of backward refraction, as well as the concentration of suspended particles in the sea water, thus the transparency of the water. The empirical results of spectral distribution and the dependence of the luminance coefficient on transparency are presented. [Text is incomplete.]

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E. N. Khalemskiy

Hydrooptical researches, completed in recent years, have /187* shown that waters of different regions of the Pacific Ocean have a coefficient of sea luminance $\rho\lambda$, that differ both in absolute magnitude and in spectral distribution. This attests to the difference of the spectral composition of energy /188 of intrinsic radiation of the sea in different sea and ocean regions.

To clarify the causes of such a phenomenon, one must first of all determine which hydrooptical characteristics exert the primary influence on the coefficient of sea luminance.

As long ago as A. G. Gamburtsev it was shown that the coefficient of diffuse reflection of the sea ζ depends primarily on two magnitudes: the absorption index and the index of backward diffusion. [1]

Actually, using a one-dimensional approximation, ζ can be expressed in the following manner [2]:

$$\zeta = \frac{1-\sqrt{1-\left(\frac{\psi}{\varkappa+\psi}\right)^2}}{\frac{\psi}{\varkappa+\psi}}, \tag{1}$$

or, taking account that

$$\frac{\psi}{\varkappa+\psi} \ll 1,$$

we obtain

$$\zeta = \frac{1}{2}\frac{\psi}{\varkappa+\psi} = K_\zeta \frac{\psi}{\varkappa}; \tag{2}$$

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*Numbers in right hand margin indicate pagination of foreign text.

where ψ , χ are the indices of backward diffusion and of absorption; K_ζ is the coefficient of proportionality.

For a calm sea we have[1] [3, 4]:

$$\rho = \zeta \frac{T'T''}{n^2}, \tag{3}$$

where T' and T" are transmission coefficients of the sea surface for radiation going from air into water and in the opposite direction; n is the index of refraction of water.

Inasmuch as the magnitudes T', T", and n do not depend on optical properties of sea water, from expressions (2) and (3) we obtain

$$\rho = K_\rho \frac{\psi}{\chi}, \tag{4}$$

where K_ρ is the coefficient of proportionality.

Thus, as equations (2) and (4) show, the magnitudes of coefficients of diffuse reflection of the sea ζ and of sea luminance ρ are determined by the ratio of the index of backward diffusion ψ to the absorption index χ.

Let us consider how the nature of special distribution of magnitude ψ/χ varies in waters of different transparency.

In turbid waters of coastal regions ($\theta<20\%$) diffusion by suspended particles is very great, and in comparision /189 diffusion of light by molecules of water can be disregarded. The basic part of suspended matter here is composed of particles of large diameter, significantly more than 2 microns, that have non-selective diffusion [5]. Therefore, the spectral distribution of magnitude ψ/χ in these waters is determined, obviously, by the special distribution of the absorption index χ.

Inasmuch as diffusion and overall attenuation of light by large suspended matter is nonselective in the visible region

[1] Here and later we have in mind the luminance coefficient, determined at the nadir.

of the spectrum [6] absorption of light by this suspended matter in turbid coastal waters is likewise nonselective. The maximum of absorption of light by water molecules is found in the long wave part of the spectrum [7]. At the same time, a dissolved organic "yellow substance," contained in great quantity in coastal waters, like a very fine suspension, has an absorption maximum in the short wave part of the spectrum [8, 9]. Therefore, the curve of absorption of turbid waters, evidently, will be characterized by a minimum in the center.

In connection with this, the magnitude ψ/χ in turbid coastal waters should decrease in the blue and red parts of the spectrum and increase in the yellow-green region.

Attenuation of light in very pure waters, for instance in the central regions of seas and oceans, where $\theta \geq 80\%$, has an altogether different character.

The concentration of suspended substances here is insignificantly small, and they are represented primarily by very fine particles with a diameter less than 1 micron [10], that are characterized by selective diffusion of light with diffusion maximum in the short wave region. The diffusion maximum of the same water is likewise located in this spectral segment, with the result that in pure ocean waters the diffusion peak occurs in the short wave part of the spectrum.

As was already indicated, absorption of light by water molecules rises in the long wave part of the spectrum, whereas absorption by "yellow substance" and by fine suspended matter increases in the blue section. However, the content of dissolved organic substances, like the concentration of suspended matter, in sea waters of high transparency is insignificant; therefore, here in the spectral distribution of the absorption index, a maximum in the short wave section is not observed or is very weakly expressed. Because of this ratio ψ/χ in very transparent waters will increase with a decrease of wave length.

As follows from formulae (2) and (4), the indicated spectral distribution of magnitude ψ/χ in waters of different transparency should correspondingly appear in the spectral distribution of coefficients ζ and ρ. In order to verify this, let us consider the actual distribution of coefficients ζ and ρ, measured in waters with different optical properties. With this goal we can use values of the luminance coefficient, obtained in /190
recent years, by the Optical Division of the Institute of Oceanography of the Academy of Sciences in various regions of the Pacific Ocean. These investigations were conducted using hydrophotometer FM-46, that makes it possible to measure the luminance coefficient of the sea in six sections of the visible region of the spectrum [3].

To guarantee a sufficiently wide range of values of the luminance coefficient, data were correlated that relate to different sea regions, but obtained in the same hydrometeorological conditions. In the selection of these conditions it was taken into account that the height of the Sun, the geometric structure of radiation incident on the surface of the sea, and the optical properties of water affect the luminance coefficient. Therefore, in order to exclude the effect of the first two factors, only values of the luminance coefficient that were measured in calm weather at heights of the Sun 35-45° in conditions of illumination of the apparatus by direct sun light were used in the experiment. The obtained curves of the spectral distribution of the coefficient of sea luminance in waters of various transparency are presented in Fig. 1.

As we see, these curves for very turbid ($\theta<20\%$) and very transparent waters ($\theta\geq80\%$) agree well with the above discussed spectral distribution of magnitude ψ/χ for these waters. A similar picture is also observed for the coefficient of diffuse reflection of the sea ζ, the spectral distribution of which was

obtained by K. Khishida [4] (Fig. 2). This is a definite confirmation of the theoretical conclusion presented above that coefficients ζ and ρ are determined by the magnitude ψ/χ.

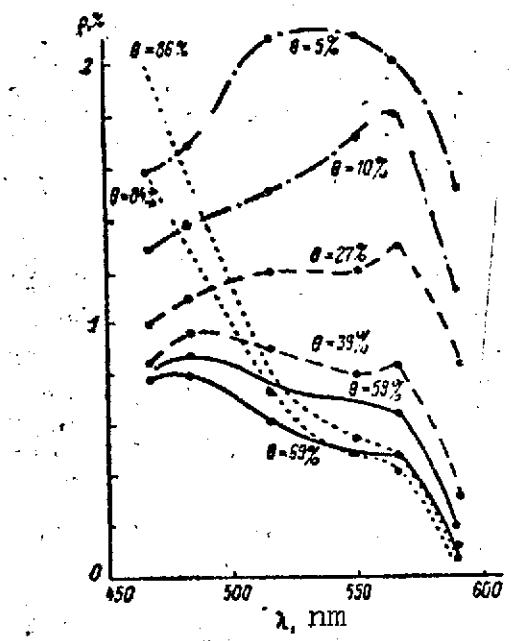

Figure 1. The spectral distribution of the coefficient of sea luminance ρ in waters of different transparency θ.

An analysis of the curves in Fig. 1 likewise makes it possible to draw some conclusions, for the investigated regions, about the nature of the variation of the luminance coefficient due to the variation of the transparency of water.

1. The absolute value of the luminance coefficient as a whole decreases in the case of an increase of transparency θ from 5 to 70%; in case of further increase of θ from 70 to 90%, there occurs a sharp growth of the luminance coefficient, especially in the blue-violet part of the spectrum. /191

2. Simultaneously there occurs a transformation of the

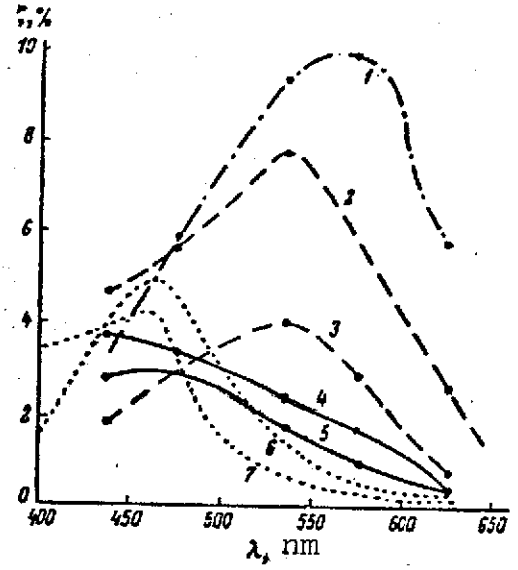

Figure 2. Spectral distribution of coefficients of diffuse reflection of the sea ς in waters of different transparency (according to [4]). 1--the Yura River; 2,3--the Mayzuru Gulf; 4,5--the Japanese Sea; 6,7--distilled water.

spectral distribution of ρ. In the case of an increase of θ from 5 to 30% the maximum of the luminance coefficient shifts from the green to the yellow part of the spectrum; at θ=40% there appears a maximum in the blue section, that [text breaks off at this point]

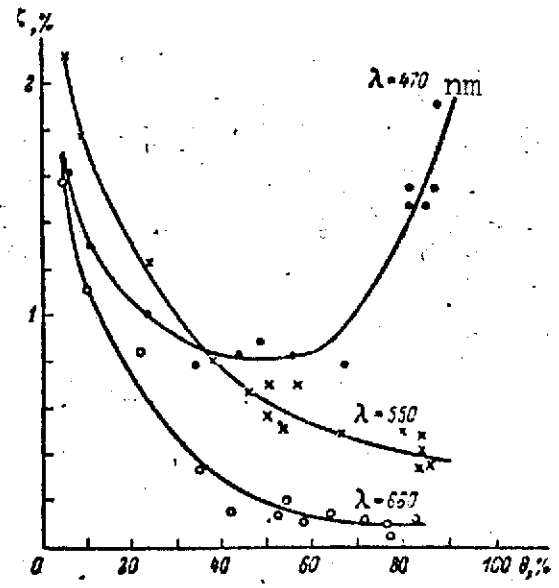

Figure 3. The dependence of the luminance coefficient of the sea θ on the transparency of water for three sections of the visible region of the spectrum.